EXERCISE 10

River Floods

"We are presently in a period of marked global increases in damage to life and property from floods and from other naturally catastrophic phenomena. The problem may be partly exacerbated by anthropogenic climatic change ("global warming"), but it is certainly tied to the human propensity to build in hazard-prone areas."

—Baker, 1994

"The reason they call them floodplains is that it is plain that they flood."

—Gore, 1995

INTRODUCTION

Tens of billions of dollars have been spent by the federal government, mainly since the 1930s, on flood control projects such as dams, levees, and channel improvements. Nevertheless, damages from flooding have continued to rise in the United States.

A flood occurs when bodies of water flow over land that is not usually submerged. Although we commonly think of floods as being caused by a river that overflows its banks during periods of excess precipitation or snowmelt, floods can also be caused by dam failures, high tides along seashores, high water levels in lakes, or high groundwater.

River floods occur when the water height (known as *stage,* and recorded as number of feet above a local base height) passes an arbitrary level. This level usually is the bank-full stage, or when a river is completely filling its channel. When a stream channel can no longer hold the increased water (its *discharge,* or total amount of water flowing past a site) and overflows its banks, then the river is said to be in flood. Water then flows on valley floors or floodplain adjacent to the normal river channel. Of course, higher discharges mean higher stages or levels of water within and outside a river channel.

Floods are a natural characteristic of rivers. They occur in response to the interaction of hydrologic, meteorologic, and topographic factors. Human actions also impact floods, for example building dams or levees, channelizing rivers, developing urban, suburban, or agricultural areas, and deforestation.

River floods are not the only types of floods. The term flood also is associated with the inundation of lake and marine coasts and alluvial fans. Even relatively flat and poorly drained upland regions are subject to flooding. In the latter case, water that would normally infiltrate to become groundwater or be carried away in poorly defined channels, sewers, or ditches remains on the land during excessive rainfall. When this water enters basements or garages, or otherwise makes life uncomfortable for the inhabitants of the area, the term flood is applied even though the area is not a floodplain, a coastal region, or an alluvial fan.

This exercise is designed to acquaint you with the nature of river floods, the problems that are created by flooding, and potential solutions. Part A analyzes flood losses in the United States, introduces the concepts of flood frequencies or recurrence intervals, magnitudes, and the variations of discharge with drainage basin area, which we consider here as intensity.

Parts B and C provide specific cases of floods. You will apply concepts and, using information from other sources, explore several solutions to flooding including those in the broad categories of (1) land use regulation and (2) engineering projects on rivers and watersheds.

Part D explores the identification of flood plains on topographic maps and the nature and use of Flood Insurance Rate Maps (FIRMs).

PART A. FLOOD FREQUENCY AND MAJOR FLOODS

Flood Discharge

The *discharge* of a stream is the volume of flow that passes a specific location in a given period of time. Discharge rates are usually expressed in cubic feet/second (cfs) or cubic meters/second (m^3/s). If the area of the wetted channel cross section (the measured width of the channel at a site multiplied by the depth of the water) and the velocity of the stream are known, then the discharge can be determined by the following formula:

$$Q = A \times V$$

where Q is the discharge, in cfs or m^3/s, A is the cross-sectional area of the stream in square feet or square meters, and V is the velocity, in ft/s or m/s.

Flood Frequency

Where flood records are available, computations of flood frequency are based on peak annual floods (the maximum discharge for the year at a specific station). Flood frequency is expressed as a recurrence interval (or return period), which is the average time interval (in years) between the occurrence of two similar floods, with the same water levels. The recurrence interval (T, in years) for a flood of a given discharge is determined by this formula:

$$T = (n + 1)/m$$

where n equals the number of years of record, and m is the rank or order of the annual flood discharges from the greatest (1), to the smallest for the number of years of record.

To understand better the impact and frequency of floods and to assist in flood prediction, one method is to plot flood data on a flood frequency graph with the discharge plotted on the vertical axis and recurrence interval on the horizontal axis. A straight "best-fit" line is drawn to join the points for each year. The average number of years that will elapse until a given magnitude flood occurs again can be estimated from this line. In other words, based on the line there is a certain probability that a flood of a given magnitude can be expected to occur x times within a fixed time interval. For example, if the recurrence interval for an annual maximum discharge of 500 cfs is found to be 4 years, then we would expect to see a discharge of 500 cfs or greater five times during a 20-year period (20 years divided by the 4-year recurrence interval).

The longer the number of years of flood records, the higher the probability is that very large floods with very large discharges have been recorded. Estimates of 100-year floods are better if they are based on 100 or more years of record. Where there are few years of flood data, such as in Table 10.1, reliable estimates of 100-year floods may be difficult.

The annual probability of exceedence, P, is the reciprocal of T. Written as a formula

$$P = 1/T$$

This is the probability or chance that in a single year the annual maximum flood will equal or exceed a given discharge. A flood having a recurrence interval of 10 years is one that has a 10 percent chance of recurring in any year; a 100-year flood has a 1 percent chance of recurring in any year.

The 100-year flood, as defined statistically, is a legal definition of areas that are likely to be flooded. If, in the United States, someone chooses to purchase a home in the 100-year floodplain, they must obtain flood insurance.

> SOMEWHERE IN THE UNITED STATES, YEAR 2000 PLUS OR MINUS. Nature takes its inexorable toll. Thousand-year flood causes untold damage and staggering loss of life. Engineers and meteorologists believe that present storm and flood resulted from ··· conditions [that] ··· occur once in a millennium. Reservoirs, levees, and other control works which have proved effective for a century, and are still effective up to their design capacity, are unable to cope with enormous volumes of water. This catastrophe brings home the lesson that protection from floods is only a relative matter, and that eventually nature demands its toll from those who occupy flood plains. (Hoyt and Langbein, 1955)

QUESTIONS (10, PART A)

Flood Frequency in the Seattle/Tacoma area

Questions 1-11 investigate recurrence intervals, 100-year floods, and changing flood frequencies for two watersheds in the state of Washington. These data are slightly modified from U.S. Geological Survey information. Population in the Puget Sound area is growing rapidly, and humans have made many changes to rivers and drainages.

Pick **one** of the four data sets (Mercer Creek 1, Mercer Creek 2, Green River 1, or Green River 2) in Table 10.1. Be sure, if you are working in a laboratory or class, that one or more students select each of the four data sets. Each data set spans 11 years of record along Mercer Creek or the Green River. Use your chosen data set to estimate the likely discharge for a 100-year flood. Follow the steps below.

1. Rank the peak flood discharges for the data set you have chosen in order of magnitude, starting with 1 for the largest and ending with 11 for the smallest. Write these results in the "Rank" column.

TABLE 10.1 Flood Data for Mercer Creek and the Green River. Discharge Data in cfs.

Mercer Creek-Data Set 1				Mercer Creek-Data Set 2			
Year	Peak Flood Discharge	Rank (1 is greatest)	Recurrence interval	Year	Peak Flood Discharge	Rank (1 is greatest)	Recurrence interval
1957	180			1979	518		
1958	238			1980	414		
1959	220			1981	670		
1960	210			1982	612		
1961	192			1983	404		
1962	168			1984	353		
1963	150			1985	832		
1964	224			1986	504		
1965	193			1987	331		
1966	187			1988	228		
1967	254			1989	664		
Green River-Data Set 1				**Green River-Data Set 2**			
Year	Peak Flood Discharge	Rank (1 is greatest)	Recurrence interval	Year	Peak Flood Discharge	Rank (1 is greatest)	Recurrence interval
1941	9310			1976	4490		
1942	10900			1977	9920		
1943	12900			1978	6450		
1944	13600			1979	8730		
1945	12800			1980	5200		
1946	22000			1981	9300		
1947	9990			1982	10800		
1948	6420			1983	9140		
1949	9810			1984	10900		
1950	11800			1985	7030		
1951	18400			1986	11800		

2. Use the formula $T = (n+1)/m$ and determine the recurrence interval of each of the 11 floods. Write the results for each year in the "recurrence interval" column.

3. Determine an appropriate vertical scale for your discharge data. The vertical scale should be chosen such that the numbers you plot from the data above fill about one-half or slightly more of the length of the scale. Write the appropriate numbers for your discharge along the left edge of the scale.

4. Plot the discharge and recurrence interval for each of your 11 floods.

5. Draw a best-fit straight line, not a dot-to-dot curve, through the data points. Extend your line to the right side of the graph.

6. Based on your data, what is the predicted discharge for a 100-year flood?

7. Either find someone who has plotted the second set of data for your stream, or repeat steps 1 through 7 to determine the predicted discharge for a 100-year flood, using the second set of data for your stream. (You may plot the second set of data on Figure 10.1; note that depending on your choice of numbers for the first plot, you may need to have a second set of values on the vertical axis.) How does your prediction made in Question 6 compare with the answer from the other set of data for the river you plotted?

8. Suggest possible human activities in the watershed that could have caused the differences in predicted floods that result from the two sets of data.

9. When you have completed interpretation of the stream you selected, find students who have done the other stream. How do their data compare with yours? What human activities did they suggest for the changes in flood predictions they discovered?

10. Based on the flood predictions for all four data sets, what does the contrast in predicted flood discharges imply about the usefulness of the 100-year flood as a legal designation for these two streams?

11. What information do you need to know if you are about to buy a house that is located adjacent to, but just outside of, the 100-year floodplain?

Large Floods in the United States

Data in Table 10.2, partly from the U.S. Army Corps of Engineers, show the damages suffered and deaths due to flooding. The U.S. Army Corps of Engineers (2000) provides data on *damages avoided* by flood projects and by emergency activities of the Corps. For example, in 1999 flood projects reduced potential damages by $2.8 billion (75% by reservoirs and 25% by levees), while emergency activities of sandbagging and technical assistance saved $48 million in losses, a much smaller amount.

Do Questions 12–16, which refer to Table 10.2.

12. On Figure 10.2, place a point for each decade to show monetary flood loss (in billions of dollars) for each decade. What is the general trend in flood loss in the United States between 1900 and 2000 as determined from Table 10.2 and your graph?

13. Now place an open circle for each decade to show the U.S. population in millions of people at the end of each decade.

14. a. For flood damage losses in the 20th century in Figure 10.2, describe and explain the trend.

b. What is the role, if any, of growth in population and rising flood losses in the 20th century?

c. What other factors contribute to increased losses?

15. Discuss the effectiveness of flood mitigation in the 20th century with your lab group. Are flood control systems effective?

16. According to the Corps of Engineers (2000), for the decade of the 1990s, the average damage loss per year was about $5 billion. For the same period the average value of flood damage reduction by projects per year is estimated at $20 billion. Using this information and that in the graphs you plotted discuss the statement "Flood-control dams and levees have been effective in reducing flood damage" and suggest additional measures for reducing flood damage.

The Discharge/Area Ratio

Questions 17 and 18 investigate ranges in flood discharge (Q) with drainage basin size (A) for several different sizes of rivers. This **flood intensity** comparison is based on data in Table 10.3, which will be plotted in Figure 10.3.

17. Use the flood records in Table 10.3 to calculate the discharge/area ratio for each river. Record your calculation in the column on the table. Plot the calculated ratio against drainage-basin area in Figure 10.3. Identify the six rivers that you are able to plot.

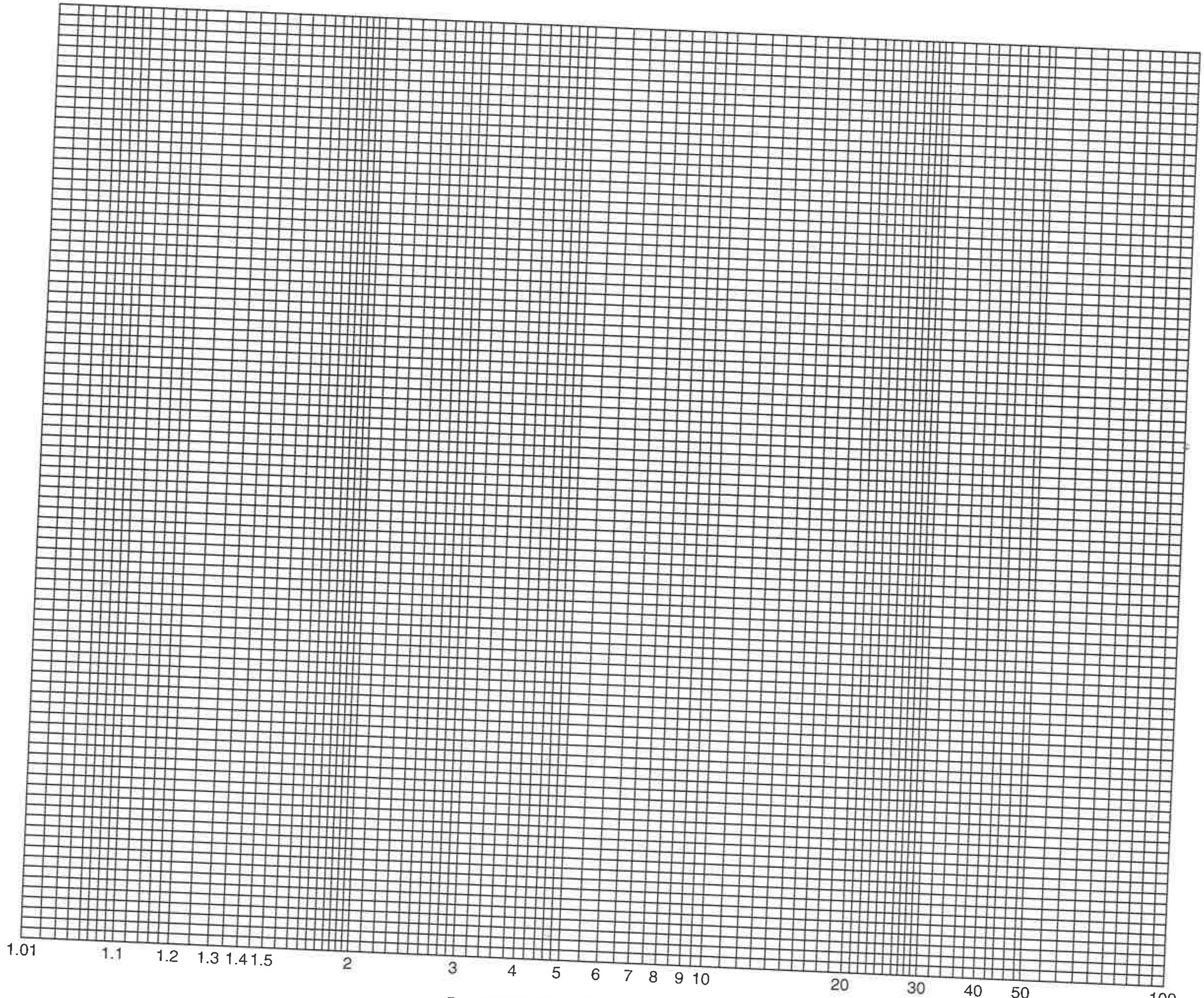

FIGURE 10.1 Flood frequency curve based on data from Table 10.1.

TABLE 10.2 Flood Damages in the United States. Monetary losses for years prior to 1993 have been adjusted to constant 1993 dollars.

Decade Ending	Flood Damages, in Billion $	Deaths	U.S. Population, in Millions
1909	7.75	204	90
1919	18.28	958	105
1929	16.31	1048	122
1939	24.07	929	131
1949	19.45	619	149
1959	28.04	791	177
1969	17.19	754	201
1979	39.88	1806	227
1989	27.49	1119	246
1999	49.56	956	273

(Flood data from Richards, 1997 and U.S. Army Corps of Engineers, 2000) population data from U.S. Census Bureau (2000).

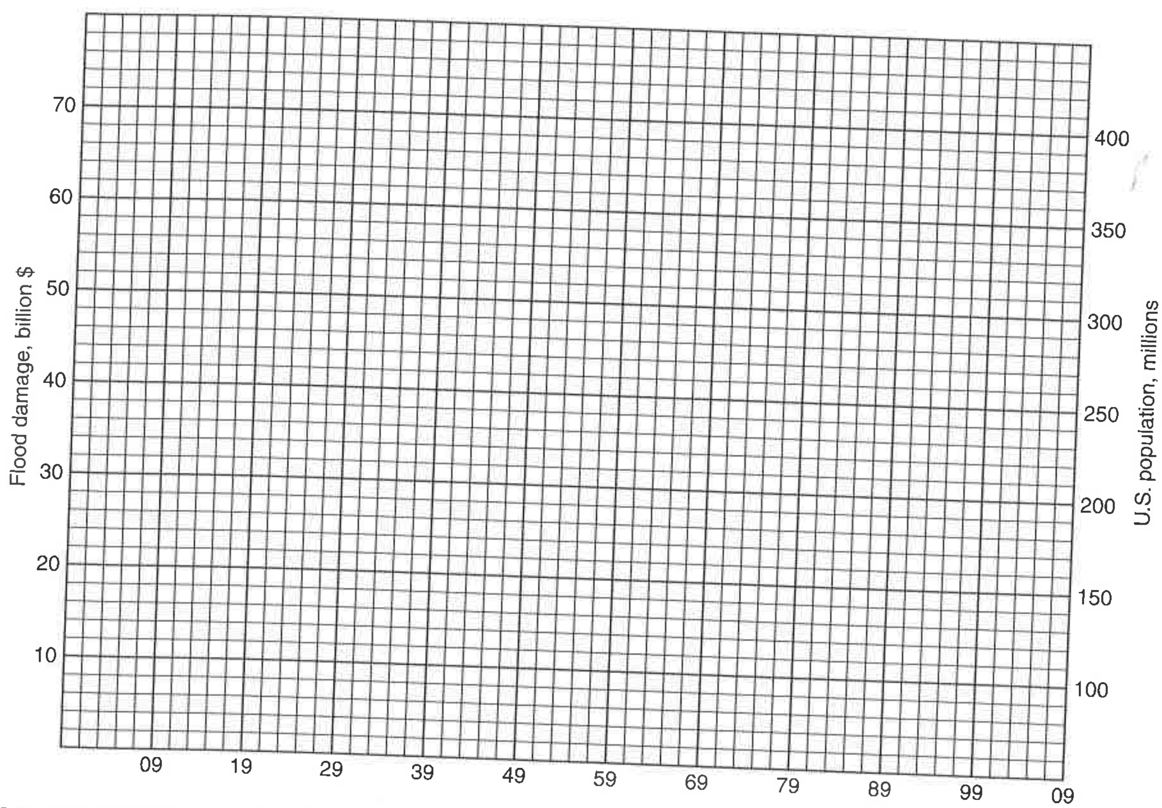

FIGURE 10.2 U.S. population and flood impacts in billions of dollars, by decade.

18. From your calculations and plots determine the general relationship between Q/A ratio and drainage basin area. With increasing area of drainage basin, is there an increase or decrease in the Q/A ratio? Briefly explain the reason for this.

PART B. ZANESVILLE, OHIO FLOOD

Flood of 1959 in Zanesville, Ohio

The Zanesville flood of January 21–24, 1959, was one of the most devastating floods since 1913 in a widespread area of Ohio. Sixteen lives were lost, damage exceeded $100 million, and 17,000 buildings were flooded. A storm on January 14–17 saturated the ground, which then partly froze and later was covered

TABLE 10.3 Discharge/Area Ratios for 9 Rivers

River		Drainage Basin Area (km^2)	Maximum Discharge, Q (m^3/s)	Q/A Ratio ($(m^3/s)/km^2$)
Name	Location			
Woallva	Hawaii	58	2,470	
Yaté	New Caledonia	435	5,700	
Pioneer	Australia	1,490	9,840	
Tam Shul	Taiwan	2,110	16,700	
Eel Scotia	California	8,060	21,300	
Han Koan	South Korea	23,880	37,000	
Cheng Jiang	China	1,010,000	110,000	
Lena	USSR	2,430,000	190,000	
Amazon	Brazil	4,640,000	350,000	

with snow. In a northeastward band extending from Cincinnati through Columbus, 6 inches of rain fell on January 20–21; more than half of the state received at least 3 inches of rain (Edelen et al., 1964).

Flood-control reservoirs in some basins reduced peak flows of some streams and prevented flood damage. The Licking River, which discharges into the Muskingum River at Zanesville (see Figure 10.4), exhibited higher flood levels in 1959 than during the 1913 flood, although 5 miles upstream from their confluence the stage of the 1913 flood was 4.5 ft higher than that of the 1959 flood.

A stream-gaging station lies on the bank of the Licking River 3.65 miles upstream from its mouth and at an elevation of 683.7 ft (Figure 10.5 map in the back of the book). The maximum stage of the 1959 flood at this gage was 32.46 ft, which means that the elevation of the flood at this point was 716.2 ft. Any structure in the immediate area of the gaging station and lower than this elevation would have suffered flood damage.

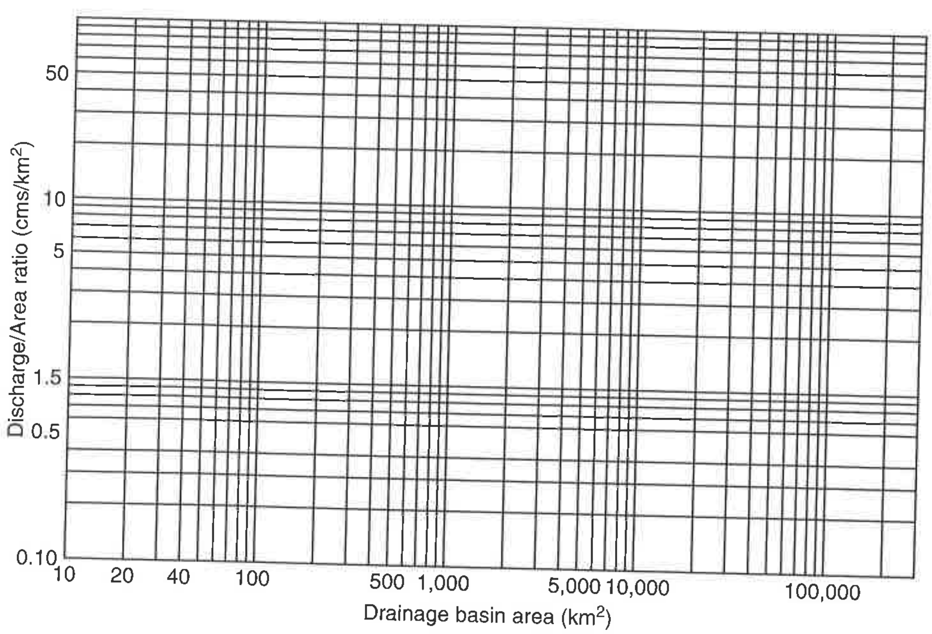

FIGURE 10.3 Variation in discharge/area ratio or flood intensity with drainage-basin area.

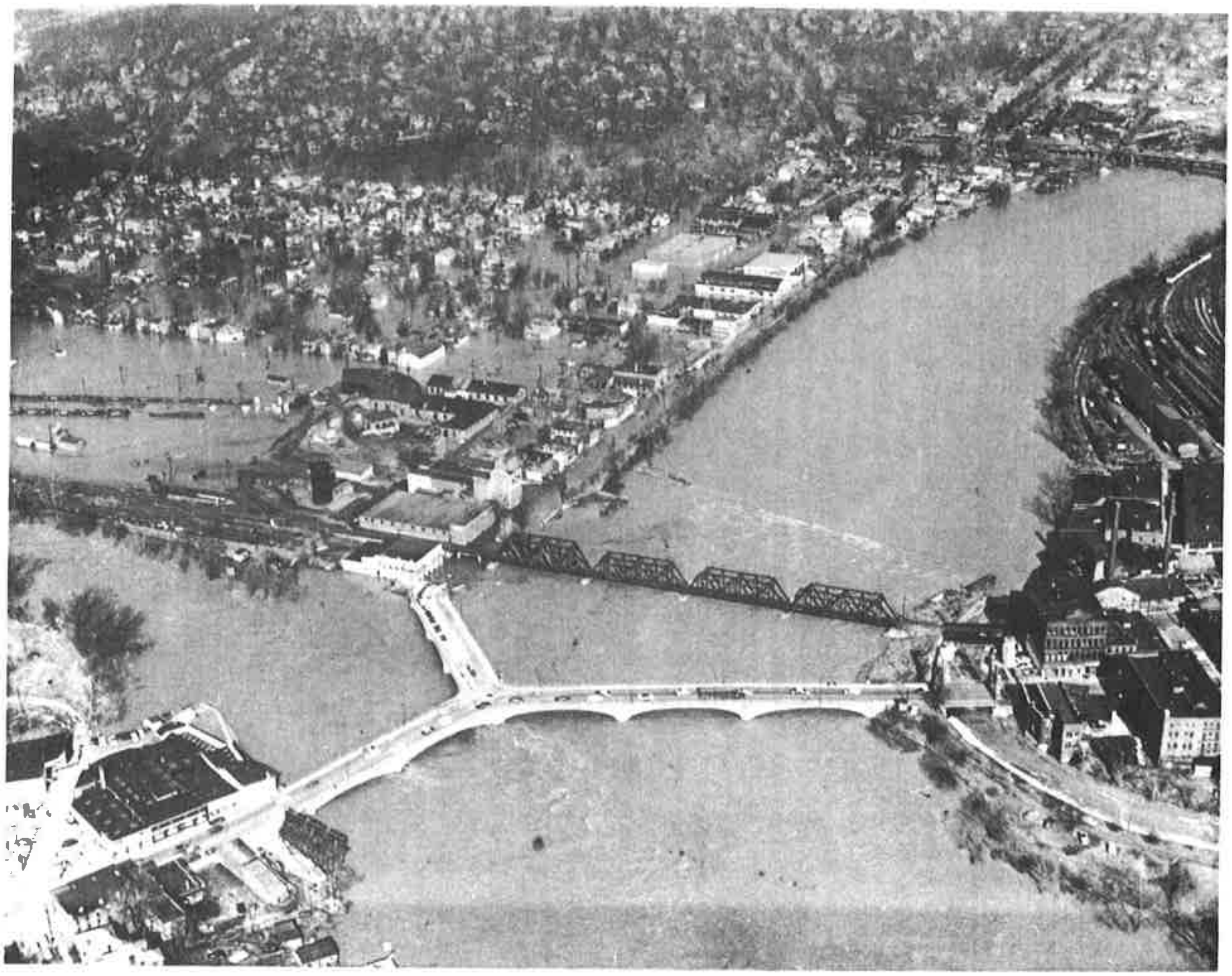

FIGURE 10.4 Confluence of Licking (left) and Muskingum (right) rivers at Zanesville during 1959 flood. (USGS, from the *Zanesville Signal*)

In this exercise we examine the extent, frequency, and causes of some river floods, and ways to reduce loss of life and property.

QUESTIONS 10, PART B

1. Using the data in Table 10.4 and the graph paper (Figure 10.6) plot the data and draw a straight line for frequency of floods at Dillon Falls, Ohio. Use a dashed line beyond the 40-year recurrence interval.

2. What are the expected elevations of the following floods at the Dillon gaging station as determined from Figure 10.6?

a. 30 years:

b. 50 years:

c. 100 years:

TABLE 10.4 Recurrence Interval, Stage, and Discharge at Dillon Falls, Ohio

Recurrence Interval at the Gaging Station (Yr)	Elevation Above Mean Sea Level, Stage (ft)	Discharge (cfs)
40	710.2	27,400
20	708.7	24,300
10	707.0	21,100
5	705.1	18,000
3	703.5	15,600

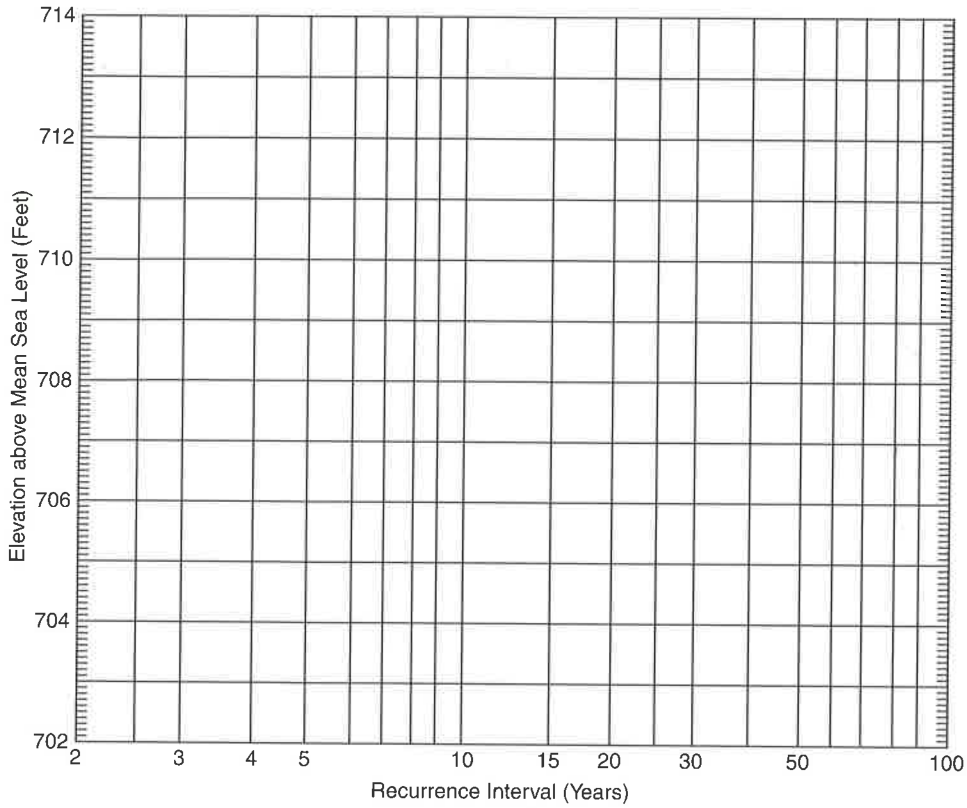

FIGURE 10.6 Frequency of floods above the 703-feet elevation on Licking River at Dillon Falls, Ohio.

3. Using the data in Table 10.4 construct a graph of elevation versus discharge (rating curve) in Figure 10.7.

4. Discharge can be obtained for a flood of a given frequency by using information on the flood frequency–elevation curve (Figure 10.6) and the rating curve (Figure 10.7). What is the expected discharge at Dillon, Ohio

a. for a 30-year flood?

b. for a 50-year flood?

5. If you visit a flood area after the water recedes, what indications might there be on buildings, trees, and land surfaces of the level of the flood maximum?

6. Figure 10.8 is a flood profile of the Licking River for the 1959 flood at Zanesville. Elevations are plotted against the distance upstream from the mouth (in miles along the centerline of the river). The maximum elevation of the 1959 flood at the gage given in the introduction. Profiles of higher or lower floods can be plotted on this diagram, although backwater effects from the Muskingum River and channel constrictions may affect the profile.

Using the 1959 flood profile (Figure 10.8) as a guide and the 40-year flood elevation at the gaging station as given in Table 10.4, determine the expected maximum stage of a 40-year flood at the floodmark elevation 2.9 miles upstream from the river mouth (Figure 10.8). Assume a similar drop in flood level (from the 1959 flood level) at the gaging station and at this floodmark elevation.

7. List several approaches that have been applied to reduce losses from river floods. (Consult your notes, textbooks, or references, if necessary.) Group the approaches as either control of the river and/or control of land use or human activity.

PART C. CENTENNIAL FLOOD ON BIG THOMPSON RIVER, COLORADO

Flash floods and associated erosion, deposition, and mass movement devastated parts of north-central Colorado in the Front Range on the night of July 31–August 1, 1976. This event caused 139 deaths and $35 million damage, mainly on the Big Thompson

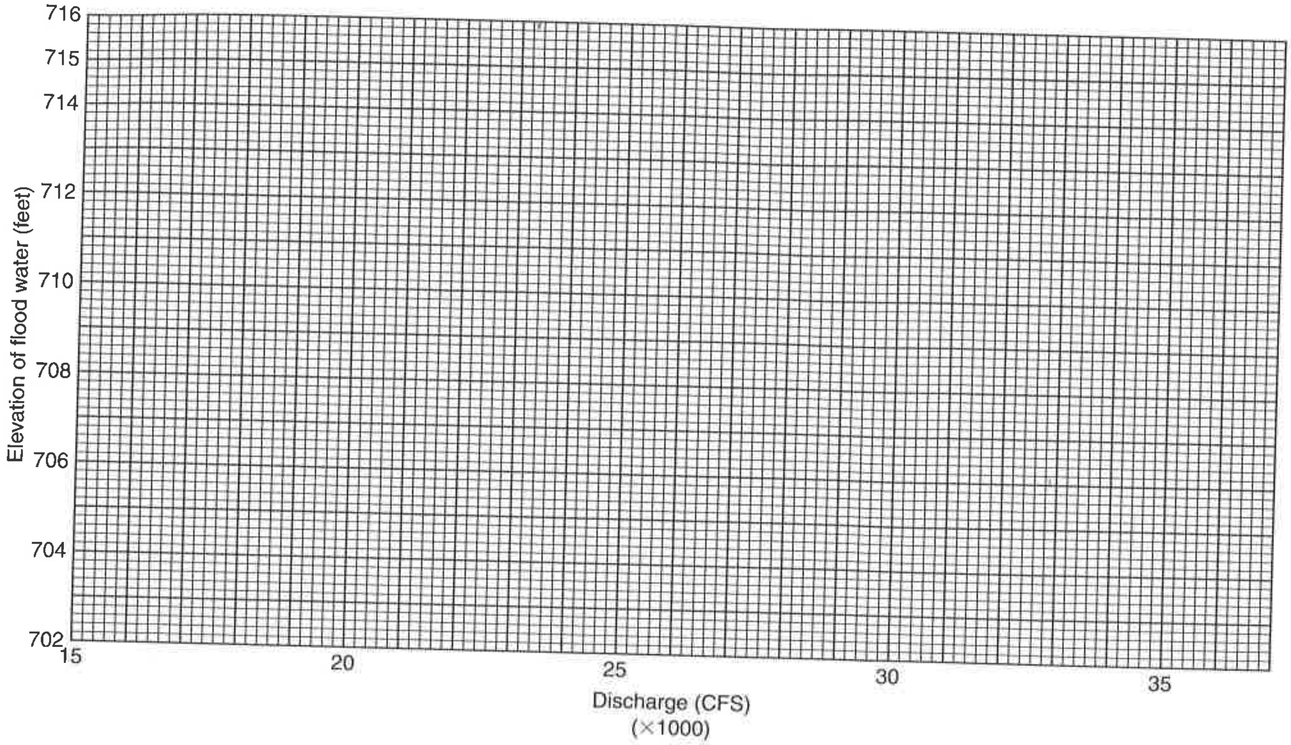

FIGURE 10.7 Rating curve for Licking River at Dillon Falls, Ohio.

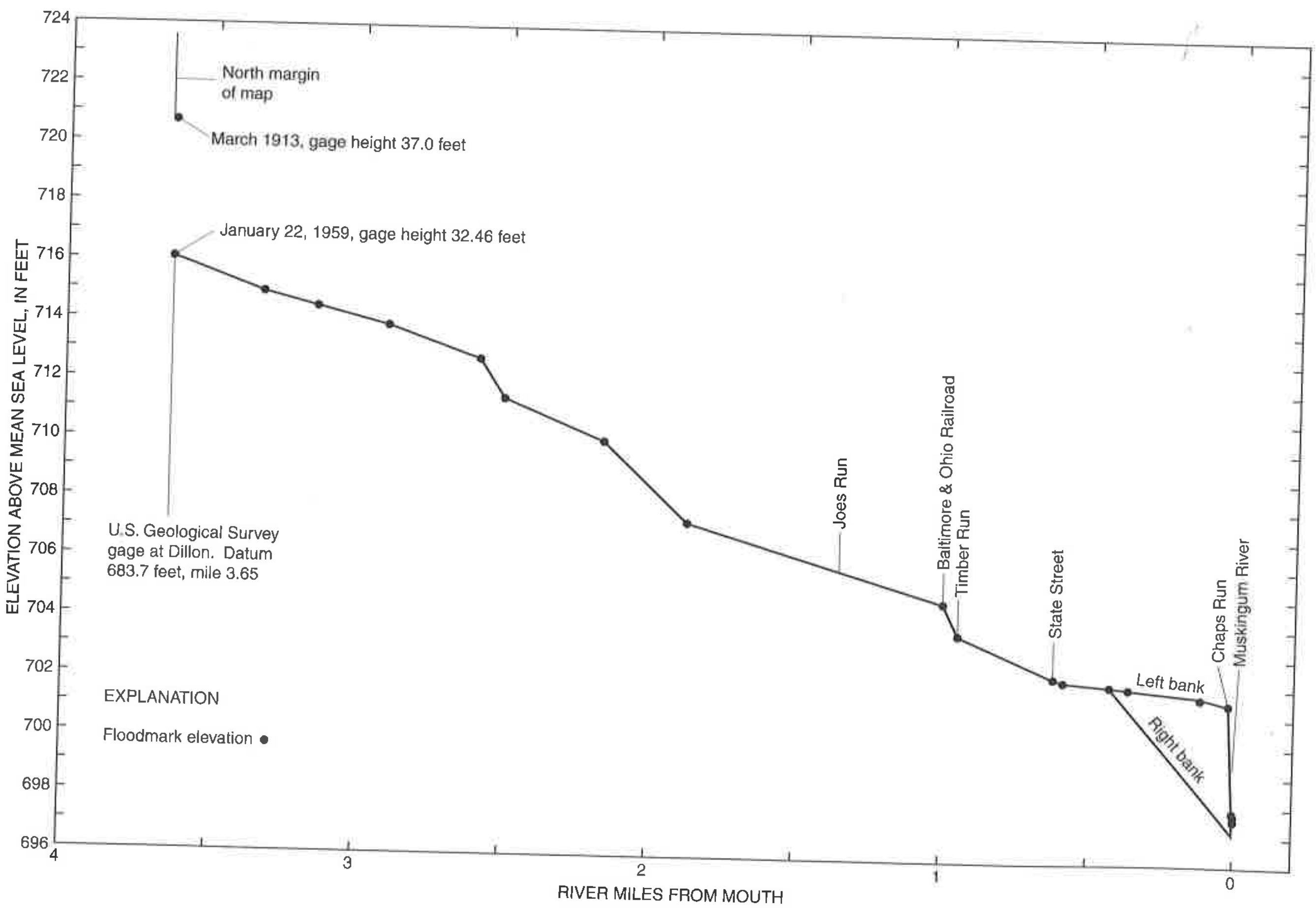

FIGURE 10.8 Profile of January 22, 1959, flood on Licking River, showing floodmark elevations (•) and influence of the railroad.

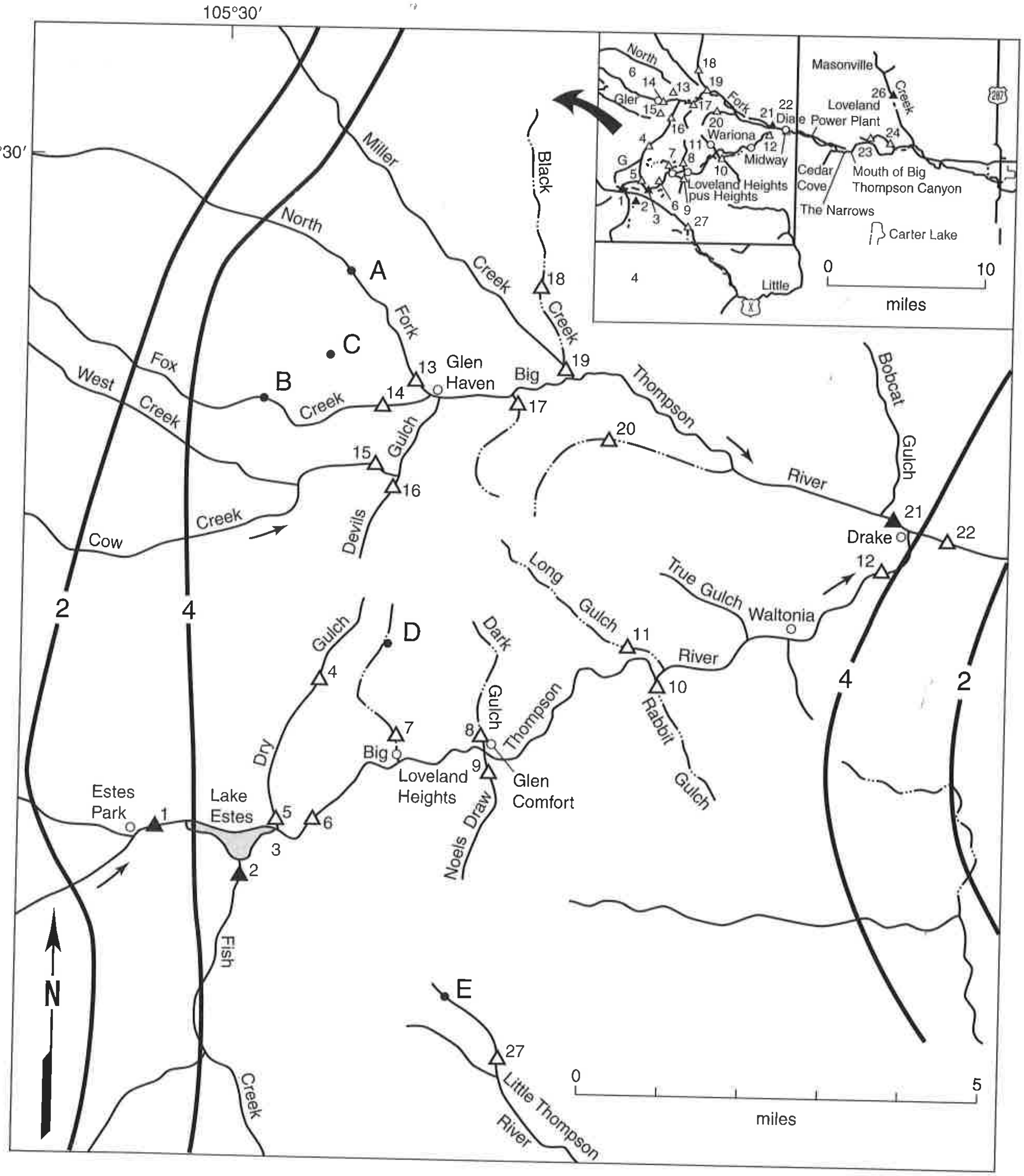

FIGURE 10.9 Location map and distribution of precipitation, in the mountains of the Big Thompson River Basin, July 31–August 2, 1976. Open and shaded triangles are discharge and precipitation sites; other precipitation sites represented by shaded circles. Isohyets are in inches. Arrows by rivers indicate flow direction.

(Base map from McCain et al., 1979; isohyets modified from Shroba et al., 1979)

River between Estes Park and the mouth of Big Thompson Canyon, 9 miles west of Loveland, Colorado (Figure 10.9).

The storms developed when moist, conditionally unstable air was pushed steadily westward up the slopes of the Front Range. By 1830 MDT (6:30 PM Mountain Daylight Time; times in this section are given in a 24-hour system, as this is how they were originally reported) a N–S line of strong thunderstorms had developed on the foothills. These nearly stationary storms intensified as additional low-level moist air flowed westward from the plains. This system locally released more than 7 in. of precipitation between 1930 and 2040 MDT, July 31. The high precipitation rate and the steep terrain caused rapid surface runoff and the Big Thompson River quickly reached flood stage.

Peak discharges exceeded the 100-year flood discharge at several sites, although the rainfall, flood discharges, unit discharges, and dollar losses were not unprecedented for areas along the eastern foothills and plains of Colorado (McCain et al., 1979). The major component of the dollar losses was damage to U.S. Highway 34; losses not counted included tax receipts, tourist business, water wells, septic tanks, and property devaluation because of location in a designated flood plain.

Significant geomorphic changes occurred in the steep terrain with relief of more than 3,000 ft and canyon walls as steep as 80 percent. These included channel scouring for most of the river, where the stream gradient was greater than 2 percent, on the outside of meander bends and in narrow reaches. In reaches where the gradient flattened to less than 2 percent and where the stream channel widened, boulders (some with an intermediate diameter of 7 ft) and finer sediment were deposited on point and channel bars and on flood-plains. Overbank sedimentation was the primary impact downstream of Big Thompson Canyon.

On the tributaries, sheetfloods transported boulders onto lesser slopes of alluvial and debris fans and eroded unprotected slopes. Debris avalanches, slides, and flows were generated by the saturated soils and provided debris that destroyed some buildings.

Both historic and geologic evidence suggests that other basins along the Front Range are vulnerable to flood events of magnitude similar to that of the one that struck the Big Thompson Basin on the eve of Centennial Sunday (Shroba et al., 1979).

The primary objective of this exercise is to understand the nature and causes of flash flooding in mountain terrains. The secondary objective is to investigate the impacts of the flooding and associated water erosion and sediment deposition. For more information on the Centennial Flood, see www.coloradoan.com/news/thompson/.

TABLE 10.5 Cumulative Precipitation, July 31–August 2, 1976, for Selected Sites in the Big Thompson River Basin. Mean value of precipitation for July here is 1.5–2.1 inches. The 2-and 4-inch rainfall contours (isohyets) are shown in Figure 10.9.

Site	Cumulative Precipitation (in.)
2	5.2
3	6.0
4	8.1
6	9.9
7	10.5
8	10.4
9	10.6
10	8.0
11	10.0
13	10.0
14	9.9
15	6.3
16	8.0
17	8.8
18	8.1
19	8.2
20	8.0
27	7.9
A	6.3
B	5.8
C	10.0
D	10.1
E	9.8

QUESTIONS (10, PART C)

1. Examine Table 10.5. Plot the cumulative rainfall for the sites in this table on Figure 10.9 and draw in the lines of equal precipitation (isohyets) for 6, 8, and 10 inches.

2. Where were the centers of precipitation?

3. What is the explanation for the intense, localized nature of this precipitation event?

4. From this map, where would you expect most flood and mass-movement damage from the storm to occur?

5. Refer to discharge hydrographs (Figure 10.10) for selected sites on the Big Thompson River and the North Fork Big Thompson River. Compare sites 1, 21, and 23. Do you think the flooding at Estes Park (site 1) was serious? Explain.

6. Do the hydrographs support the precipitation data in indicating the area(s) of greatest runoff and potential damage? Explain.

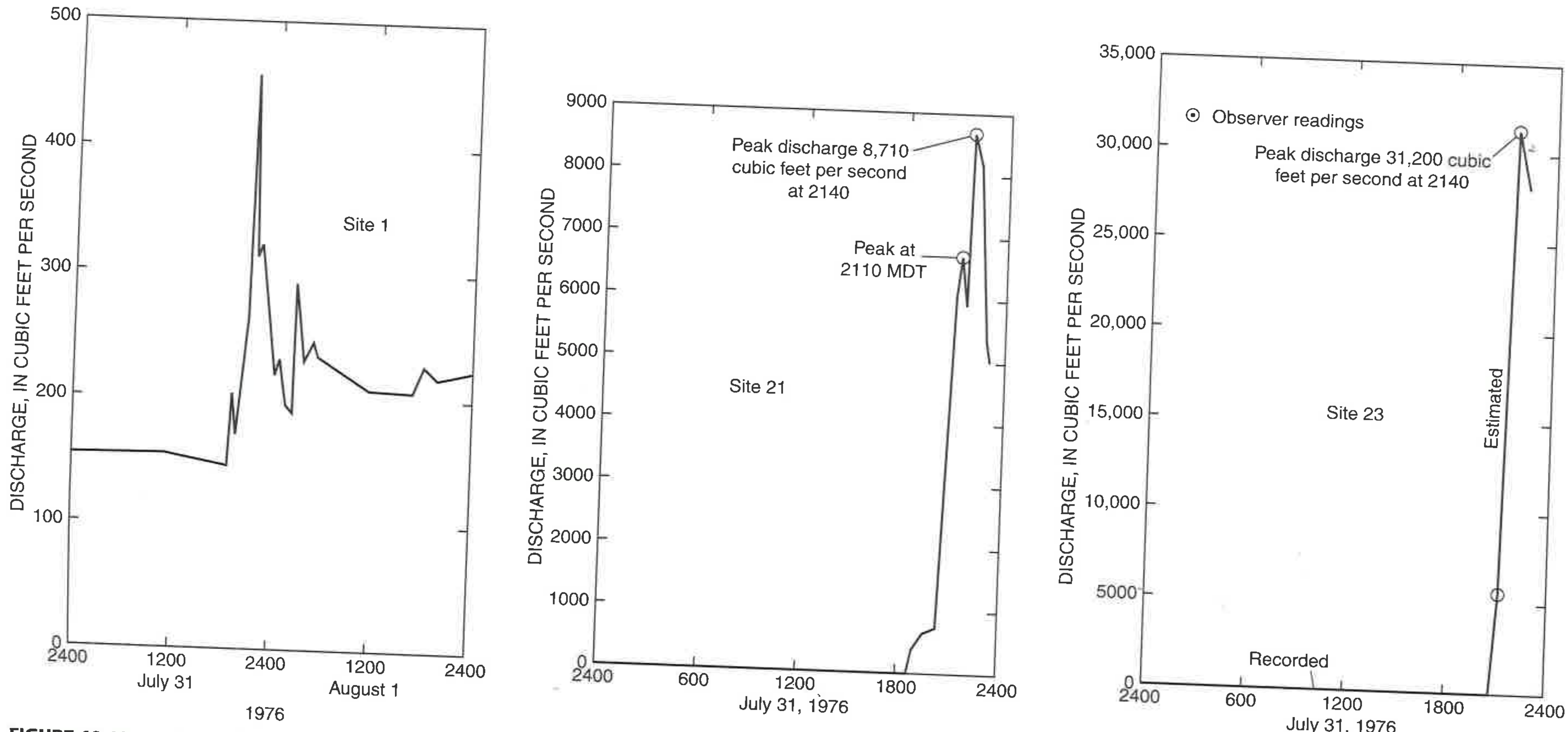

FIGURE 10.10 Hydrographs for Big Thompson River (Sites 1 and 23) and North Fork Big Thompson River (Site 21). Bottom scale is in hours, using a 24-hour clock. See Figure 10.9 for site locations (McCain et al., 1979).

7. There are two major rivers in the Big Thompson River system: The Big Thompson (BT) in the south and the North Fork Big Thompson (NFBT) in the north. The flood peak at site 22, east of Drake, occurred at the same time as the minor peak at site 21 (2110 MDT) on the NFBT (see Figure 10.9).

a. How did the flood crest moving down the BT impact the water level on the NFBT at Site 21?

b. Why was there a second (main) peak at Site 21 on the NFBT?

8. If the main peak at site 21 had occurred 30 to 35 minutes earlier than shown in Figure 10.10, what impact would this have had on the size of the flood at site 23 at the mouth of Big Thompson Canyon (Figure 10.9, Inset map)?

9. The flood crest reached Site 23 at the mouth of Big Thompson Canyon, 7.7 miles east of Site 22, 30 minutes after the crest at Site 22. What was the average speed of the flood crest in miles per hour and feet per second? Could you outrun this flood crest?

10. Refer to Table 10.6

a. At what three sites were the unit discharges or discharge/area ratios of drainage basins (cfs/mi^2) the greatest?

TABLE 10.6 Hydrologic Data for Selected Flood Sites in Figure 10.9

Site No.	Stream and Location	Drainage Area (mi^2)	Peak Discharge (cfs)	Unit Discharge (cfs/mi^2)	Average Velocity (ft/s)	Average Depth (ft)
4	Dry Gulch	2.00	3,210	1,600	12	3.3
6	Big Thompson R., Lake Estes	9.00[a]	4,330	481	8	4.6
7	tributary near Loveland Heights	1.37	8,700	6,350	26	5.5
8	Dark Gulch	1.00	7,210	7,210	28	5.1
9	Noels Draw	3.37	6,910	2,050	21	5.7
10	Rabbit Gulch	3.41	3,540	1,040	13	4.7
11	Long Gulch	1.99	5,500	2,760	19	5.8
12	Big Thompson R. above Drake	34.0[a]	28,200	829	22	8.3
14	Fox Creek	7.18[b]	1,300		9	2.8
16	Devils Gulch	0.91	2,810	3,090	12	2.1
17	Tributary near Glen Haven	1.38	9,670	7,010	29	5.6
18	Black Creek	3.17	1,990	628	11	4.5
20	Tributary west of Drake	1.26	3,240	2,570	18	3.0
21	North Fork Big Thompson R. at Drake	85.1[b]	8,710		12	5.2
22	Big Thompson R. below Drake	276.[b]	30,100		16	10.3
23	Big Thompson R. at mouth of canyon	305.[b]	31,200		26	10.6

a. Approximate contributing drainage area during flood of July 31–August 1, 1976.
b. Contributing drainage area for flood of July 31–August 1, 1976, unknown.
(from McCain et al., 1979)

b. How do the locations of these sites compare with the distribution of maximum precipitation for the storm (see Figure 10.9)?

11. Plot the peak discharge and drainage area for each of the stations with the three highest unit discharges for the 1976 storm on the peak discharge/drainage area diagram for eastern Colorado (Figure 10.11). Unit discharges provide a measure of the relative size of a flood event in cubic feet per second per square mile (cfs/mi^2). Considering the three data points plotted for the 1976 flood, do you think that even more outstanding floods will occur on Big Thompson River, or is this the largest that can be expected? Explain.

12. Explain why unit discharge for Site 23 (see inset map, Figure 10.9) could not be plotted on this graph (Figure 10.11; see Table 10.6.)

13. From Table 10.6, which site had the highest average velocity of stream flow?

14. Given that the previous peak discharge at Site 21 was 1290 cfs in the 1965 flood, how many times larger was the 1976 flood than the earlier flood at this site?

15. The ratio of the peak discharge of the 1976 storm to the discharge for the 100-year flood was determined for selected stations as follows:

Site	Peak Discharge, 1976 (cfs)	Ratio
12 (BT)	28,200	3.8:1
21 (NFBT)	8,710	1.4:1
22 (BT)	30,100	2.9:1
23 (BT)	31,200	1.8:1

For the drainage basins upstream of Drake, was this flood greater on the Big Thompson River (BT, Site 12) or on the North Fork Big Thompson River (NFBT, Site 21)?

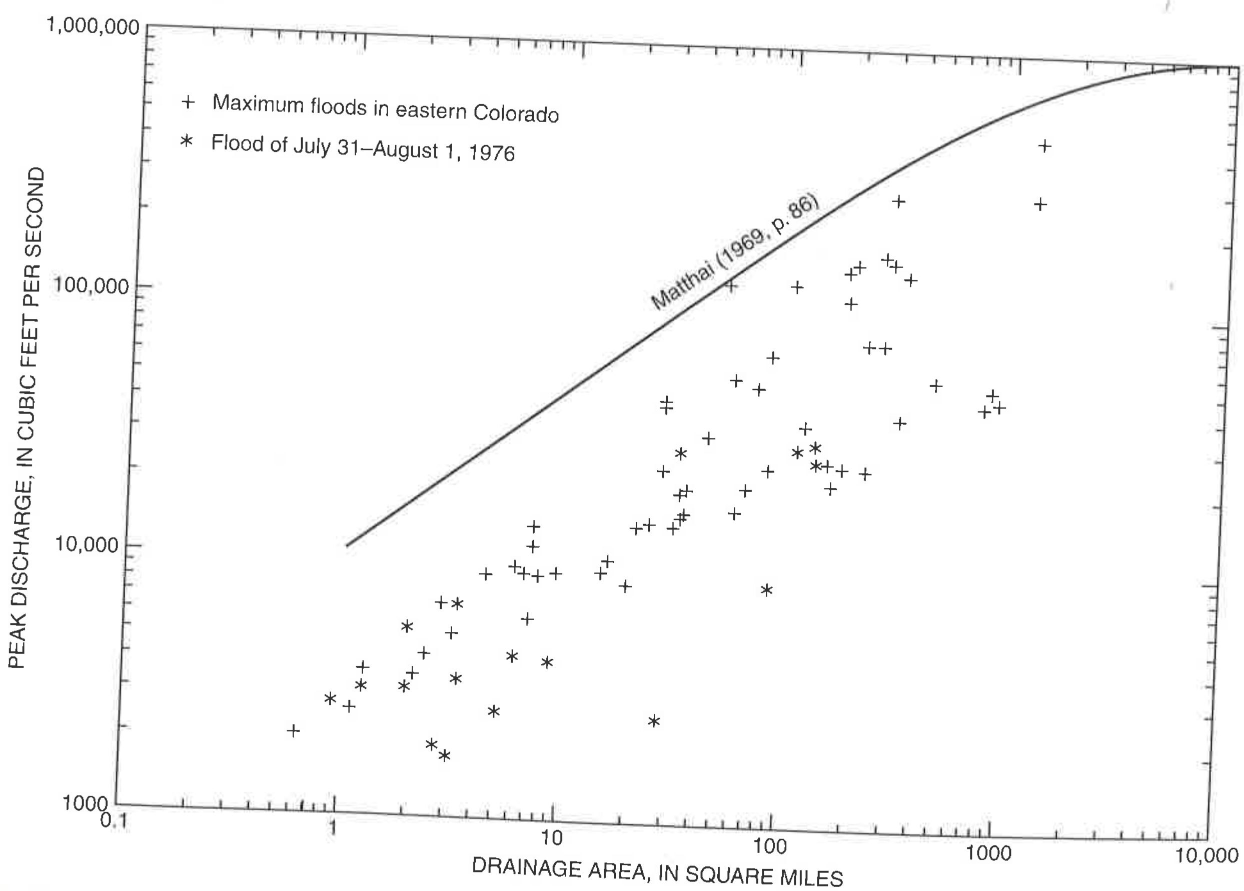

FIGURE 10.11 Relation of peak discharge to drainage area for flood of July 31–August 1, 1976, and previous maximum floods in eastern Colorado. The curve was drawn through the average of the eleven largest floods in the United States between 1890 and 1969. The empirical equation for the curve below the 200 mi^2 area is Q = 4000 AO.61, where Q = discharge and A = drainage area.

(Modified from McCain et al., 1979; after Matthai, 1969)

16. Using the information in Question 15, what is the expected discharge for the 100-year flood? (Hint: The ratio shown is: discharge for 1976 storm/discharge for 100-year flood.)

17. Study Figure 10.12 showing the Waltonia area before and after the flood. Describe the changes in buildings, roads, vegetation, and stream bed.

18. At other sites along the river, significant changes (erosion and deposition) also occurred on the floodplain and on alluvial and debris fans. Large accumulations of boulders and debris occurred on some of the fans; other fans underwent erosion. Study Figure 10.13. Would it have been safer to reside during the 1976 storm on the inside or outside of a meander? Explain.

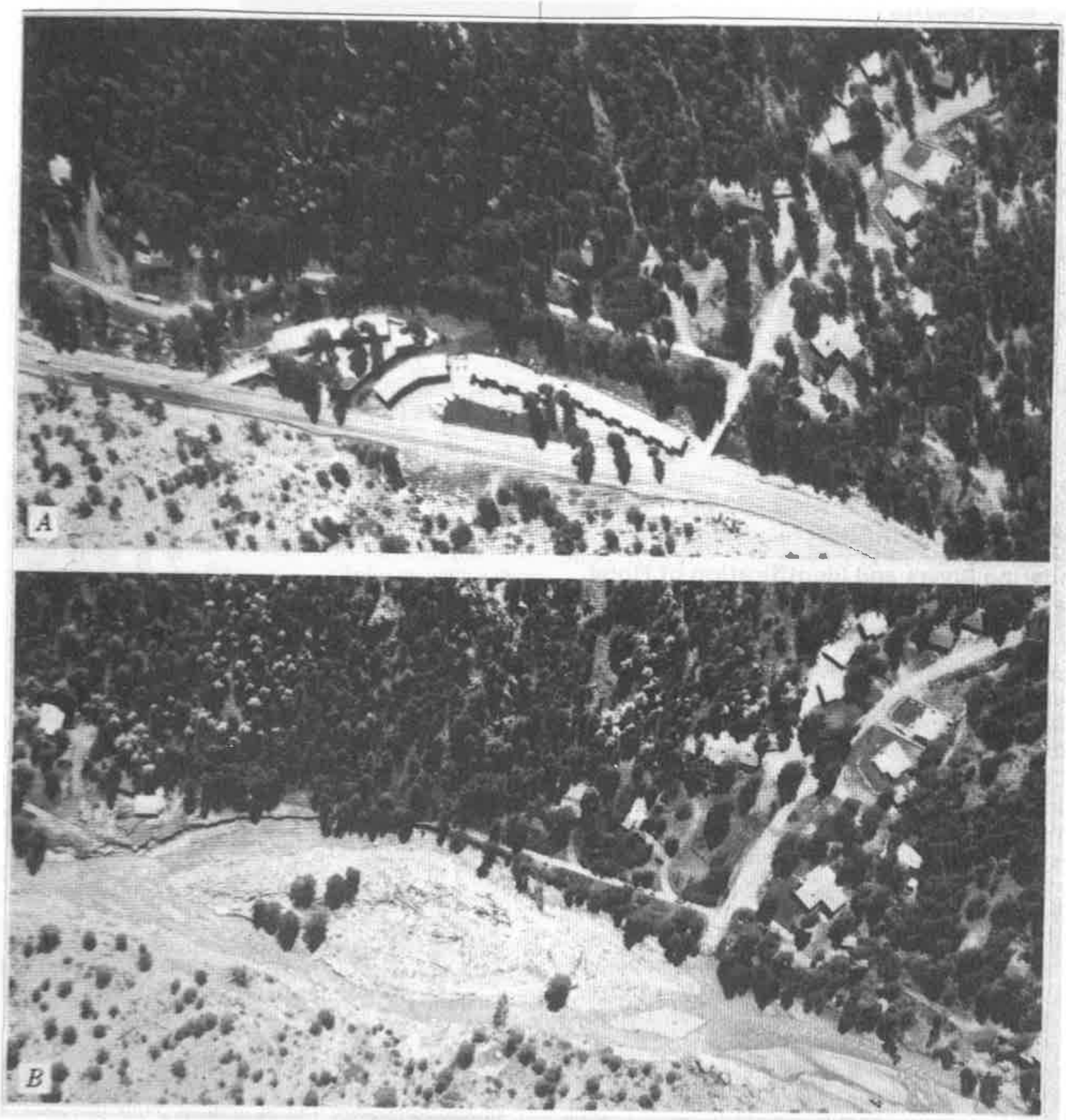

FIGURE 10.12 Aerial photos of Waltonia, 1.5 miles southwest of Site 12 before (A) and after (B) the flood. Approximate scale: 1 in. = 200 ft. Most of the community is on a debris fan. Highway 34 and two large motels are shown in the floodplain in A. Big Thompson River is immediately behind (north of) the motels (Shroba et al., 1979).

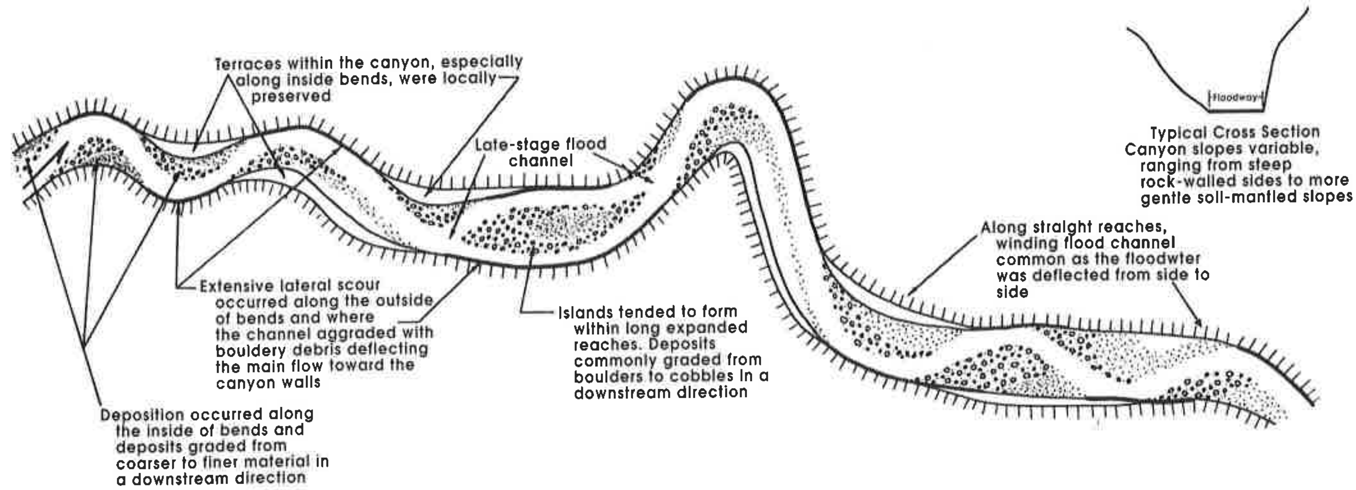

FIGURE 10.13 Pattern of scour and deposition within canyons of Big Thompson and North Fork Big Thompson rivers. Floodway is about 200 ft wide with gradients of 2–4 percent (Shroba et al., 1979).

19. The heaviest precipitation from this flood occurred between 1930 and 2040 hours MDT at Glen Comfort and 1930 and 2200 hours at Glen Haven. There was little opportunity to warn anyone. Use this information with the other information in this exercise to prepare two paragraphs, one arguing for and the other against purchase of a waterfront lot for a house in one of the many river valleys or canyons similar to Big Thompson along the Front Range of the Rockies. Use a separate sheet of paper for your answer.

PART D. FLOOD PLAINS AND FLOOD INSURANCE RATE MAPS

Meandering Rivers and Identification of Flood Plains on Topographic Maps

The first step in avoiding flood hazards is to avoid building in rivers. Some geoscientists suggest that the area known as the flood plain should instead just be called part of the river. The implication of this is important: Flood plains are natural parts of river systems that do not happen to be covered by water all of the time. When flood plains are covered by water, however, the damage to unprepared (and in some cases even prepared) people and communities can be disastrous.

In this part of the exercise we are going to use several different topographic maps in the colored plates section of the book, and identify different flood plains on the maps. First, refer to Figure 10.14, which is a sketch of typical topographic features seen along a flood plain.

Note on this figure that natural rivers meander (bend) a lot. The floodplain is the topographically low area adjacent to the river. Although when we look at a river it may appear to have a permanent channel, meandering rivers will change their channels and erode and redeposit over their entire floodplain, given enough time. The river determines how much time is "enough"; it may be a few years, a few decades, or a few centuries. But over time, rivers will occupy and modify their floodplains.

On a shorter time period, floods will cover parts of the river valley. How much gets covered is determined by how big the floods are.

QUESTIONS (10, PART D)

Refer to Figure 2.10 in Chapter 2, Bloomington, Indiana.

1. Sketch a topographic profile of the valley of Griffy Creek, from the 750′ contour in contact with the "L" in Bloomington in the west to the zero in the 750′ contour above the "16" in Township 16 in the East. Mark the floodplain on the profile with a different color.

2. Is the Drive-in Theater (Southwest of the dam) in a floodplain? Explain.

3. Is Payne Cemetery (east-central part of the map) in a floodplain? Explain.

Refer to Figure 6.10 in Chapter 6, Draper, Utah.

4. Shade on this map the floodplain of Little Cottonwood Creek in the area of Glacio Park, near the eastern edge of the map.

5. Do you think the floodplain west of Beaver Ponds Springs is broad or narrow? What evidence do you use to support your answer?

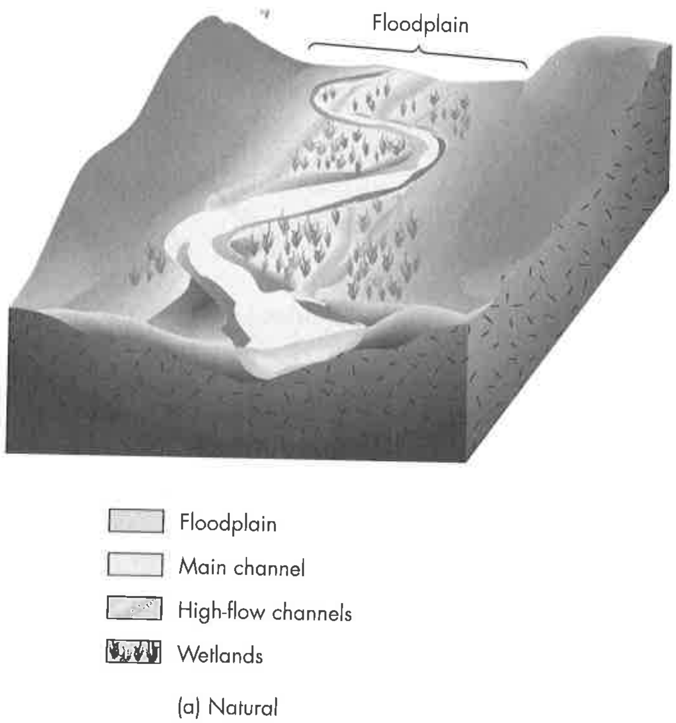

FIGURE 10.14 Components of a floodplain.
(Modified from Keller, 2002).

Refer to Figure 8.23 in Chapter 8, Athens, Ohio.

6. Shade on this map (1975), the area of the Hocking River floodplain from the Fairgrounds to the Radio Tower.

7. Are any buildings located on the floodplain? Identify three of the major ones.

8. What has happened to the course of the river through time in the area south of the sewage disposal facility?

Flood Insurance Rate Maps

In 1968, Congress created the National Flood Insurance Program. Flood Insurance Rate Maps (FIRMs) are part of this program. According to the FEMA website (http://www.fema.gov/pdf/fhm/ot_frmsb.pdf), flood information on FIRMs is based on historic, meteorological, hydrologic, and hydraulic data, as well as the amount and types of open space, the existence or absence of flood control works, and the status of development. FIRM are used to determine if homeowners need to obtain flood insurance. It is less expensive to own a home if you do not have to pay for flood insurance.

It is important to note that FIRMs represent a "snapshot" in time, as they reflect the conditions in existence at the time of the creation of the map. Should weather patterns change, perhaps as local or regional manifestations of global climate change, should the amount of open space change, should flood control works be installed or removed, or should the status of development change with population growth, FIRMs may quickly become outdated.

For example, if an area upstream from a site along a river is changed from forest to urban, the amount of water that runs off (goes rapidly to streams rather than soaking into the ground or being used by plants) increases dramatically. In wooded or rural areas, typically 5–30 percent of the rainfall runs off, while in business and industrial areas, 50–90 percent of the water runs off and in residential areas 25–70 percent of the water runs off. The amount of runoff will also depend on other factors such as the density of development in an area, the types of soils, the angle of hillslopes, and the intensity and duration of individual storms. In general, however, development leads to a 2–3 times increase in the amount of runoff (Iowa Department of Transportation, 2004).

Washington, DC

Figure 10.15 is a FIRM map of part of Washington, DC. The left side of the map is the Potomac River. Rock Creek flows into the Potomac from the east. The circular "Zone C" on the east side of the river is centered on the Lincoln Memorial.

9. Let's first look at the background (nonflood) information on the map. What types of background data are shown on the map?

10. What types of background data are missing from the map that would be helpful in identifying flood hazards?

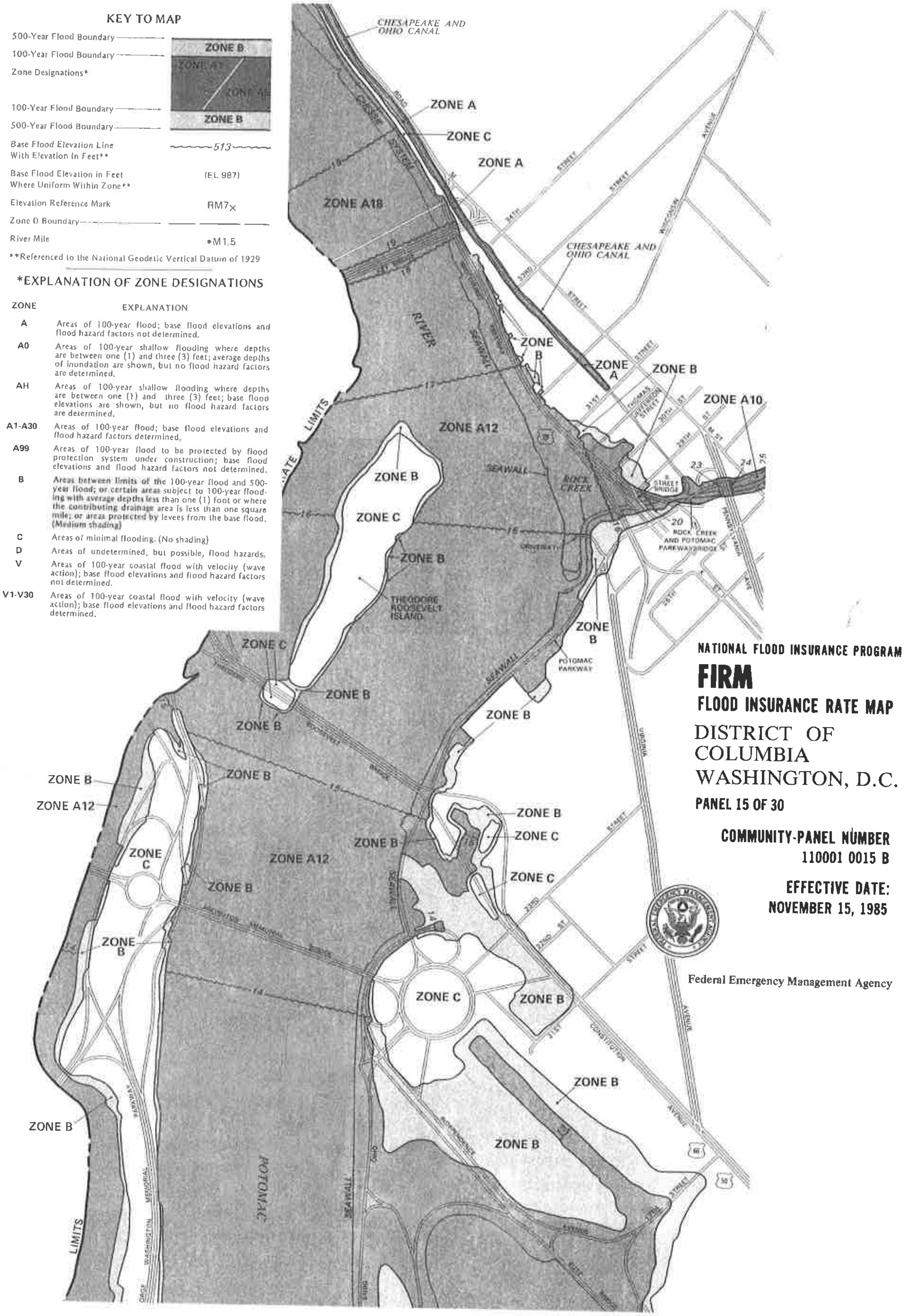

FIGURE 10.15 Flood Insurance rate map of part of Washington, DC.

11. What hazard zones are identified on the map? How often are floods expected in zone A? In zone B?

12. Are areas in zone C are completely free from flood hazards?

13. Are all the hazard zones on the map the result of natural processes? Look carefully and explain.

14. Although the data that comprise flood hazard depictions on this map were collected in 1974 and revised in 1975, what year was this map published? What changes might have taken place in this area between the time the data were collected and the map was published?

15. What year is it now? What additional changes do you think might have taken place in the drainage basin of the Potomac River? What will be the likely impact of these changes on flood hazards that have been mapped?

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